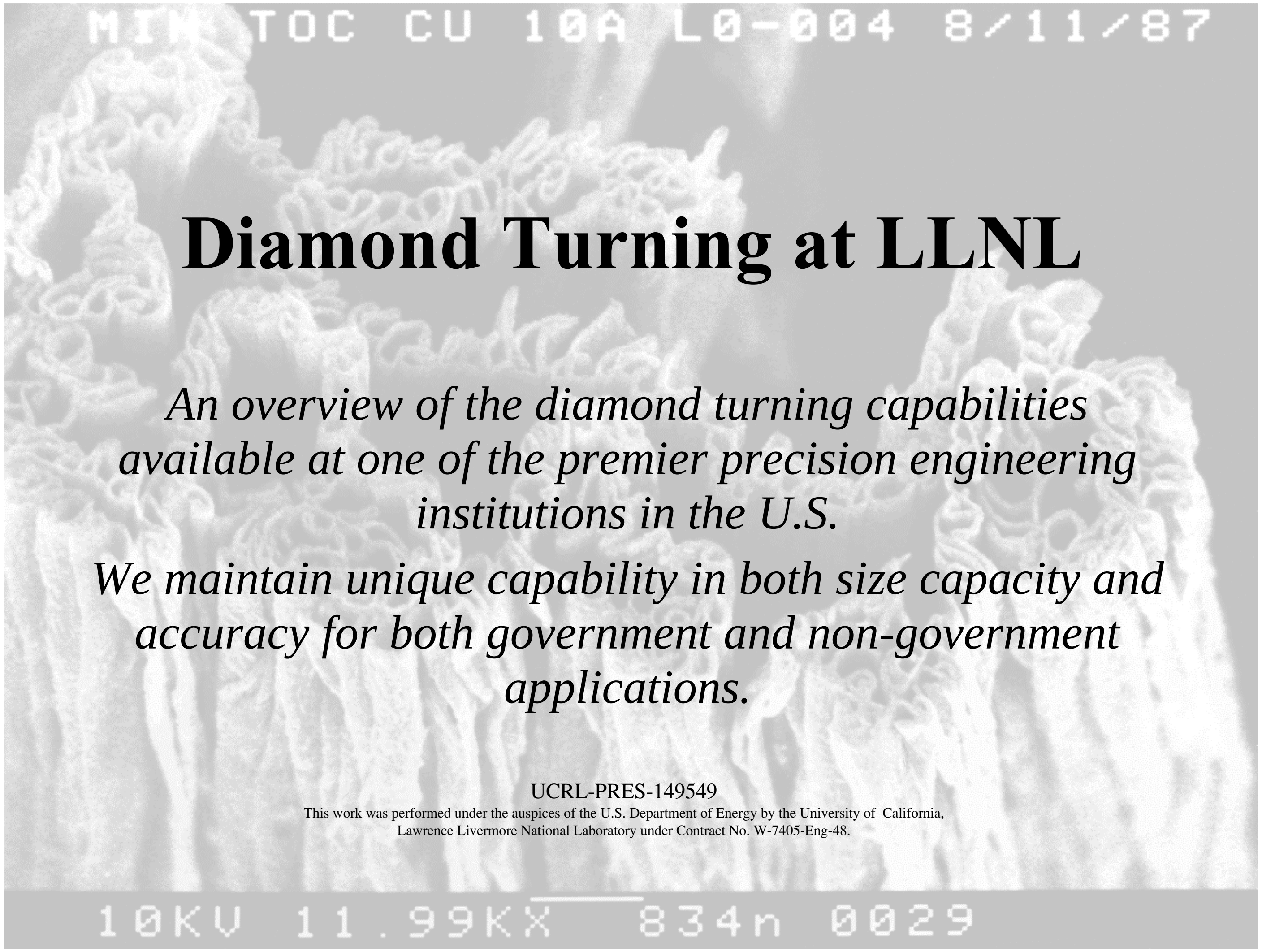

Diamond Turning at LLNL

An overview of the diamond turning capabilities available at one of the premier precision engineering institutions in the U.S.

We maintain unique capability in both size capacity and accuracy for both government and non-government applications.

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A historical view of diamond turning

- Tracer lathe accuracy enhancement was needed to improve weapon's components. A deterministic approach to designing machines evolved at LLNL.
- Using atomically sharp diamonds as cutting tools was discovered at Oak Ridge-Y12 and LLNL.
- Moore Special Tool evolved LLNL's DTM2 machine design into the first commercial diamond turning machine, the M18 Aspheric Generator.
- At LLNL the focus was on higher accuracy and larger size capacity. The machines on the next pages addressed these needs.
- The success of these higher performance machines at LLNL has led to the "ultra-precision" commodity diamond turning machines used in the contact lens, eyeglass, and molded optic industries.

DTM 2 operating with oil shower active

Current State of Diamond Turning at LLNL

- The LLNL-built machines still maintain a separation from their commercial counterparts. High *absolute* accuracy is possible by:
  1. Maintaining strict thermal control
  2. Using independent metrology frames and systems
  3. Complying to the Abbé and Bryan principles

Absolute accuracy is important in that it allows parts to be made non-iteratively.

- Key to the success of fabrication and metrology with these machines is the experience base of 10 machinists with a cumulative 100 man-years of experience building, operating and maintaining machines.

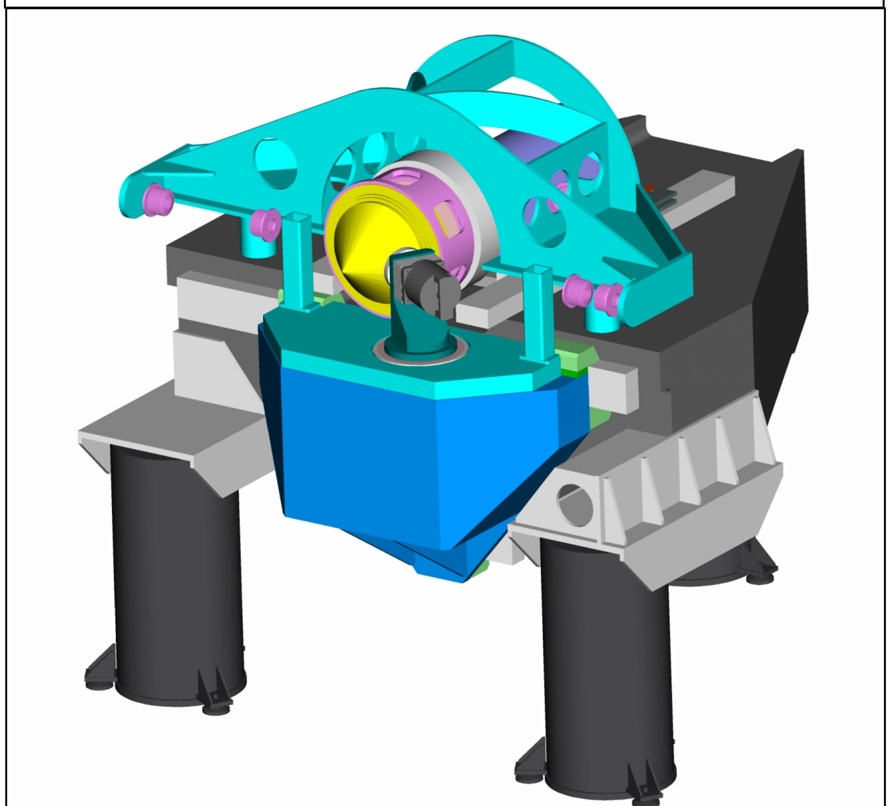
Machine	Max. Diameter meter (inch)	Accuracy μ m, P-V(λ, rms)	Surface Finish Å rms
PERL II	0.15 (6)	0.10 (λ/25)	25
LODTM	1.65 (65)	0.10 (λ/25)	50
DTM 3	2.44 (96)	1.00 (λ/2)	300
POGAL*	0.40 (16)	0.05 (λ/60) goal	10 goal

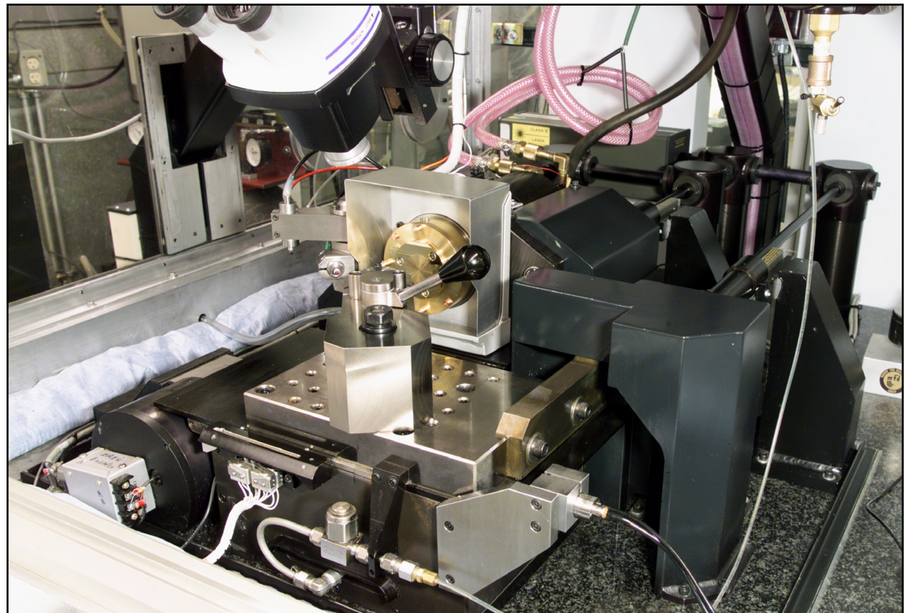
These machines and experience offer a unique combination of capabilities that are only invoked when a commercial vendor cannot meet the desired requirements.

* POGAL is currently in design with expected deployment during 2003

Small Machines and Capabilities

Precision Optical Grinder & Lathe (POGAL)
- 400-mm diametral capacity
- Grinding capability
- B-axis (tool) rotary table
- Fully compensated motion control
- 2003 deployment



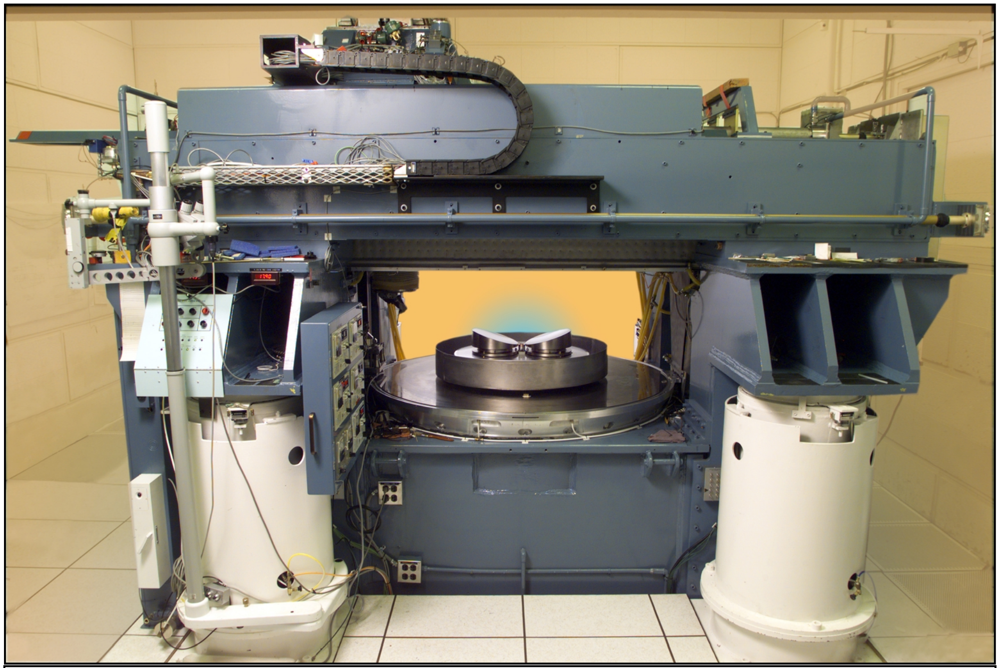


Precision Engineering Research Lathe (PERL)
- Small parts, < 100-mm diameter
- Accuracy < 25-nm
- Stiff structural loop for excellent surface finish

Large Machines and Capabilities

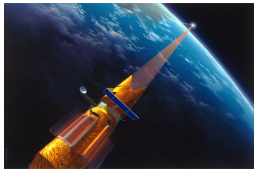
Diamond Turning Machine 3 (DTM 3)

- Largest size capacity, 2.3-m diametral
- Independent kinematic metrology
- Oil shower thermal isolation



Large Optics Diamond Turning Machine (LODTM)

- Vertical axis lathe
- 1.5-m diametral by 0.5-m axial capacity
- Fully compensated motion control
- 25-nm rms accuracy



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Spaced-based Laser (SBL) Resonator Optics

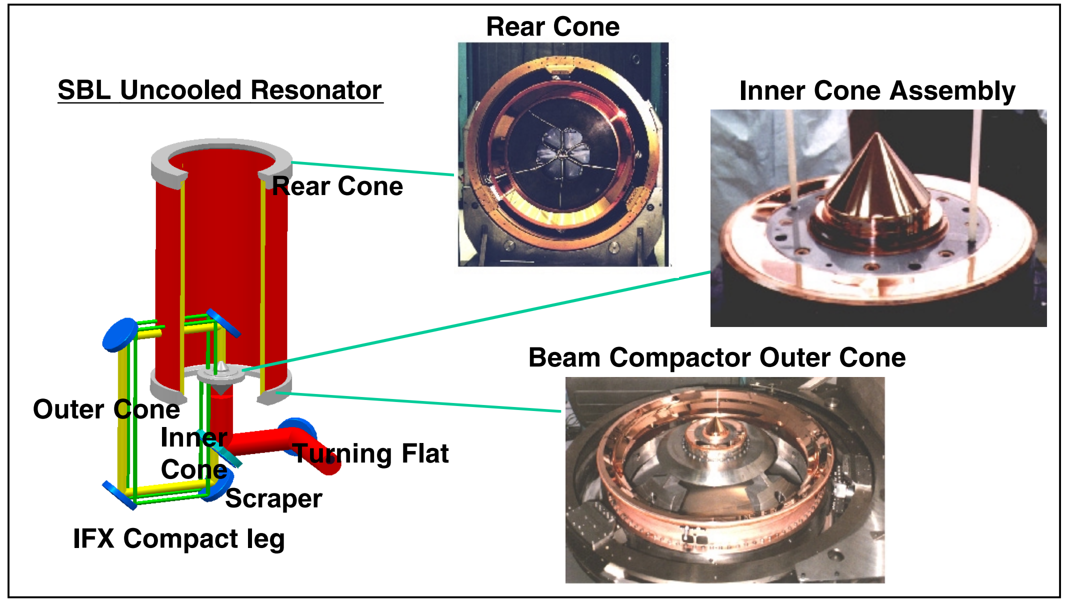
• The annular design of the laser cavity for the Space-based Laser leads to very small tolerances on the optical surfaces of the cavity optics.

• After much effort was expended in conventional polishing approaches to fabricating the four optical surfaces, the LODTM was proposed and built to make the Alpha chemical laser cavity optics via diamond turning.

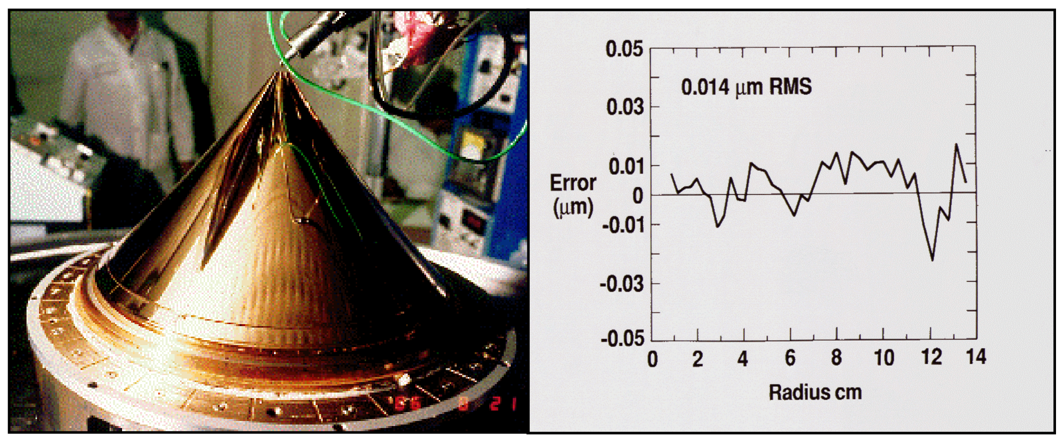
• The optics fabricated on LODTM met the tolerance requirements and performed successfully in the laser test.

• Since that work (mid-1980's), the focus has been on fabricating silicon resonator optics. While some progress has been made, it will be very difficult to directly diamond turn silicon to the finished optical surface requirements.

• We see a critical role in the Space-based Laser Program for the LODTM for final metrology and possibly also with an iterative material removal process such as magneto-rheological finishing (MRF).



Schematic of the Space-based Laser

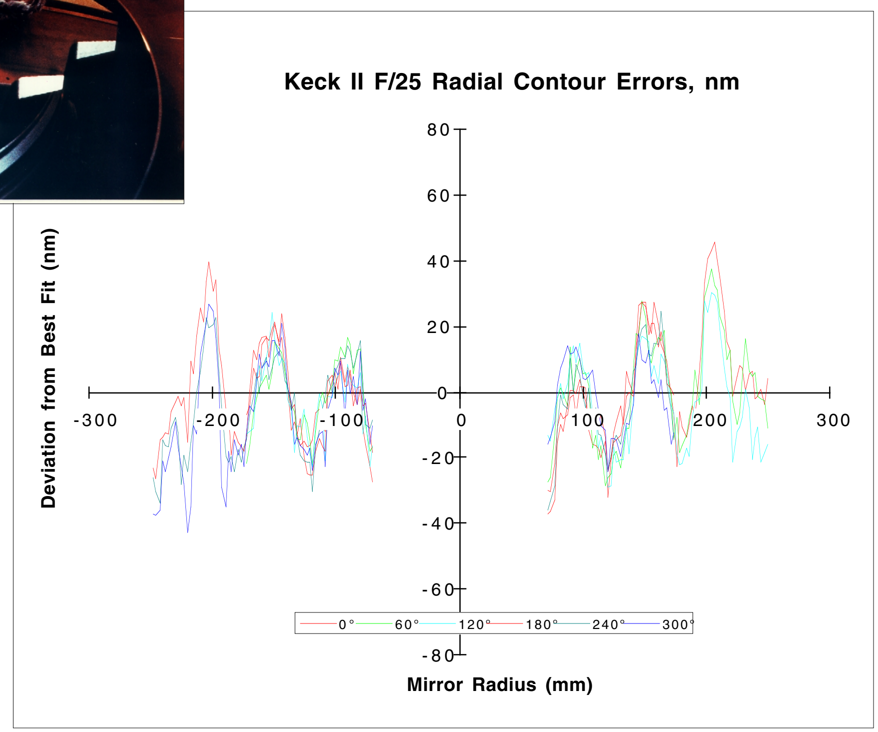


Copper clad molybdenum inner cone and contour error plot

Keck Telescope IR Secondary Mirrors

- Overfilled mirror, which is an image of the primary, to assure stray-light rejection.
- Therefore the surface figure must be accurate to edges of the mirror; i.e. no rolloff.
- The secondaries are chopping mirrors (~30 Hz) and so they are lightweight beryllium substrates with an electroless nickel overcoating that is diamond turned.
- The mirrors were successfully diamond turned on the Large Optics Diamond Turning Machine (LODTM) at LLNL to 80-nm P-V figure as shown at right.

Keck Telescope secondary mirror on the LODTM



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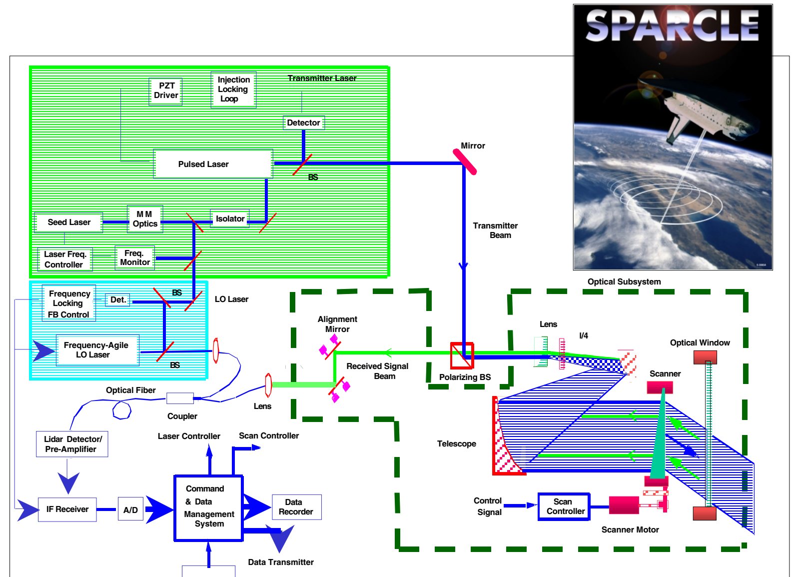
SPARCLE–SPAce Readiness Coherent Lidar Experiment

• Accurate global wind fields are the most important measurement remaining in the effort to understand how atmospheric winds affect our climate. SPARCLE, NASA's first demonstration of a coherent Doppler wind lidar in space, will be flown on a future Shuttle mission.

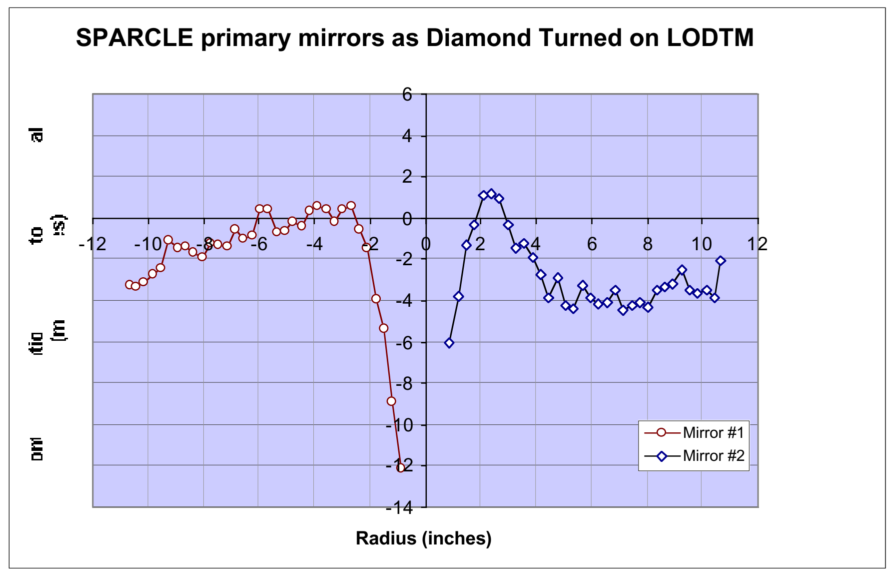
• The critical primary mirror is a 250-mm f/0.9 mirror, 150-mm off axis. The figure requirement is _/4 P-V @ 633-nm.

• The mirror is an aluminum substrate, "rough diamond-turned" on DTM3 to 2-µm tolerances, nickel plated and then diamond turned to the final tolerances on LODTM. The graph at the right shows the profiles of the two mirrors.



SPARCLE Schematic

SPARCLE primary mirror shown on the LODTM faceplate with NASA engineer Holly Cagle



Future Directions for Diamond Turning at LLNL

- The following are areas that we see potential for applying our experience and infrastructure to enable programs of national importance and the possibility for collaboration outside LLNL.
  - Precision grinding of optics on diamond turning machines: Replacing the diamond tool with a grinding process allows access to many more materials, including beryllium. An important piece to maintain, however, is the displacement-based (high-stiffness) accuracy of the diamond turning machine. With high loop stiffness and accurate metrology, extremely good optical figure can be obtained. In the case of beryllium, this can offer considerable cost savings by reducing the very long polishing times now needed.
  - Magneto-Rheological Finishing (MRF) on diamond turning machines: Similar to above except now the MRF process would be a final finishing process and the diamond turning machine would give high accuracy metrology. A material of interest here is silicon for the optics for the Space-based Laser.
  - Cost-effective, lightweight optics for space telescope applications: Aluminum is an attractive material for many applications if it can be figured to the required tolerances. Diamond turning offers potential for low cost fabrications of aspheric optics.